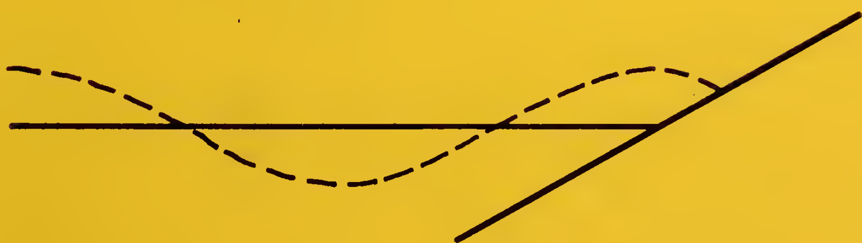
Gulf Coast Low Water Datum

January 1977



U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

Gulf Coast Low Water Datum

Office of Marine Surveys and Maps
Oceanographic Division

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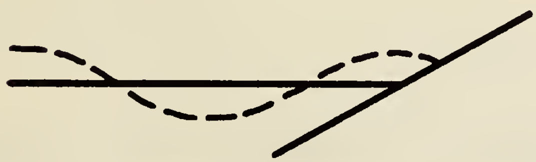

U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

National Oceanic and Atmospheric Administration
Robert M. White, Administrator

National Ocean Survey
Allen L. Powell, Director

STATEMENT OF INTENT

The intention of the National Ocean Survey, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, is to designate GULF COAST LOW WATER DATUM as Chart Datum for the coastal waters of the Gulf Coast of the United States.

GULF COAST LOW WATER DATUM will be defined as *mean lower low water* when the type of tide is *mixed* and *mean low water* when the type of tide is *divrnal*.

The demarcation between Chart Datum of the Atlantic Coast (*mean low water* of the *semidiurnal* type of tide) and Chart Datum of the Gulf Coast will occur at the boundary between the *semidiurnal* tide of the Atlantic and the adjacent *mixed* tide of the Gulf. The boundary from *mixed* to *semidiurnal* will occur where the value of the ratio of the principal diurnal constituents of the tide to the principal semi-diurnal constituents becomes less than .25.

SUMMARY

The National Ocean Survey plans to establish a uniform, continuous, tidal datum to be used as a low water reference elevation along the entire Gulf Coast of the United States. This elevation, to be known as Gulf Coast Low Water Datum, will provide:

1. One uniform low water datum name for the entire Gulf Coast, and

2. one continuous low water reference elevation based on the same tidal characteristics.

Essentially, Gulf Coast Low Water Datum is a new name which, when applied to certain existing datums in a prescribed manner, will form the desired continuous reference elevation. It will be used:

1. As the base from which depths and contours on nautical charts and bathymetric maps are referred;

2. for determining the position of the low water line when used on charts and maps; and

3. to fix those coastal boundaries that are formed by, based upon, or measured from (or points thereon) the low water line.

Adoption of Gulf Coast Low Water Datum will:

1. Eliminate the confusion and contradiction that presently exists with respect to the actual datum names, the names they are called, and the technical definitions associated with each;

2. reduce the necessity of lengthy, defensive, detailed explanations in courts and in legal depositions;

3. eliminate vertical datum jumps and the resultant abrupt horizontal displacements of coastal boundaries;

4. possibly cause minor adjustments of the position of the low water line as depicted on very large scale charts as the result of new hydrographic surveys; and

5. eradicate interpretive controversies over the application of low water datums in coastal boundary problems, thus ensuring equitable divisions to all parties concerned.

PREFACE

This document presents and explains the intention of the National Ocean Survey (NOS), as approved by the National Oceanic and Atmospheric Administration (NOAA), to establish Gulf Coast Low Water Datum. It comprises the conclusions and recommendations of Cdr. Carl W. Fisher, NOAA, Chief, Oceanographic Division, Office of Marine Surveys and Maps (MS&M), NOS; Carroll I. Thurlow, Deputy Chief, Oceanographic Division, and Acting Chief, Tides and Water Levels Branch, Oceanographic Division; Edward D. Evans, Jr., Office of the General Counsel, NOAA; and Steacy D. Hicks, Physical Oceanographer, MS&M; with contributing advice from R. Adm. Robert C. Munson, NOAA, Director, Atlantic Marine Center, NOS, and James W. Brennan, Deputy General Counsel, NOAA. R. Adm. Munson, as former Associate Director, MS&M, initially sponsored the project. Continued sponsorship is being provided by Capt. Richard H. Houlder, NOAA, Associate Director, MS&M. This document was written by Steacy D. Hicks.

The conclusions and recommendations are based on the extensive work of two committees over the last two years.

The Oceanographic Division Committee on Gulf Coast Datums was composed of:

Robert A. Cummings
Jack E. Fancher, II
Steacy D. Hicks, MS&M, Chairman
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I. INTRODUCTION

Boundaries are as old as civilization itself. The first, and still the most common, are those defined by geologic conformations; including such features as mountain ridges, cliffs, rivers, and ocean shores. The usual requirement is to be easily recognizable by all parties concerned and to be relatively permanent. Their origin, at least, was intrinsically involved with defense. In recent centuries, series of artifical markers, parallels of latitude, meridians of longitude, and other lines recoverable by surveying techniques were added. However, by far the oldest, and seemingly the most logical, are boundaries associated with the line where land and ocean meet.

The word "seemingly" is very important. While land-ocean boundaries are so very logical on first assessment, their logic rapidly becomes more vexing when *in situ* and map (and chart) positioning accuracy, precision, recoverability, and etymology are concerned.

Since the ocean (and land) moves up and down in both periodic and nonperiodic motions, the location of the land-ocean intersection line moves up-the-beach-landward and down-the-beach-seaward as a function of time. If this intersection is to be used as a boundary (or the source of a boundary), it must be stopped from this horizontal movement; that is, it must be mathematically "fixed" by man. It follows that to fix the land-ocean intersection line in its landward-seaward movement, the up-down motion of the water must likewise be mathematically "fixed."

It is also desirable to fix the up-down motion of the water surface to obtain a reference for depths and depth contours on nautical charts and bathymetric maps; and finally, a reference is needed for tide prediction elevations.

A mathematically fixed elevation of the ocean surface is known as a tidal datum. It is fixed through officially adopted definitions and procedures of the National Ocean Survey. The definitions and observation-based procedures are a function of the type of tide prevailing in the area of consideration.

The consistency of the types of tide on the West and East Coasts of the United States precludes significant problems. However, along the Gulf Coast the type of tide varies both in time and distance. Exact knowledge of these differences and changes has been accumulating very slowly as the network of National Ocean Survey tide stations has progressively expanded over the years. As a result of this slow accumulation of tidal data, the best tidal datum decisions were made with the best knowledge available <u>at the time</u>. Thus, conflicting concepts inadvertently developed over the years which have contributed to confusion in several subject areas of land-ocean boundaries and depth references. The confusion over inconsistencies can no longer be disregarded. This is true in view of the findings of the comprehensive Louisiana coastal survey completed in 1960 and, especially, the present Florida coastal survey.

Escalation of waterfront property values and questions regarding the jurisdiction to receive oil-tax revenues accentuate the urgency for resolving the problems. Also, various offshore boundaries (all except one of which are

based on land-ocean boundaries) are now receiving wide attention in many law-of-the-sea considerations. The President's signing of the Fishery Conservation and Management Act of 1976 (P.L. 94-265, 94th Congress) on April 13, 1976, precipitated the necessity for a solution to these inconsistencies along the Gulf. The 200-mile limit is fundamentally based on chart datum. Although any adjustment in the datum will probably be within the accuracy of the total boundary delineation method, it is imperative that the method be defensible in international and national law. With flaws in the fundamental datum (regardless of how small), the delineation method (no matter how sound) will be suspect and challengeable.

II. TYPES OF TIDE

There are three basic types of tides: semidiurnal (semidaily), mixed, and diurnal (daily).

A. The first type, semidiurnal, has two high waters (high tides) and two low waters (low tides) each tidal day. A tidal day is the time of rotation of the earth with respect to the moon and its mean value is approximately equal to 24.84 hours. Qualitatively, the two high waters of each tidal day must be almost equal in height for this classification. The two low waters of each tidal day also must be almost equal in height.

B. The second type, mixed, is the same as the semidiurnal except that the two high waters and/or two low waters of each tidal day must, qualitatively, have marked differences in their heights. An example (the actual tide curve at Clearwater Beach, Florida, for April 1975)

is shown in figure 3. Its location is shown in figure 1. When there are differences in the high waters, they are designated as higher high water and lower high water; when there are differences in the lows, they are designated higher low water and lower low water. If there are marked inequalities in both the high and low waters, the sequence of tide can either be higher high, higher low, lower high, lower low; or higher high, lower low, lower high, higher low.

C. The third type, diurnal, has one high water and one low water each tidal day. (See figures 1 and 4.)

The type of tide can vary both with time at a single location and in distance along the coast. (See figures 1, 2, and 5.) The transition from one type to another is gradual. As such, there has to be a definite cutoff point if precise definitions are to be meaningful. The following is the accepted quantitative classification system of the National Ocean Survey for type of tide (Marmer, 1951, after Van Der Stok, 1897):

$$R = \frac{K_1 + O_1}{M_2 + S_2}$$

TYPE	
Semidiurnal	R = < 0.25
Mixed	R = 0.25-1.50
Diurnal	R = > 1.50

where:

R = ratio,

K_1 = amplitude of lunisolar diurnal constituent,

O_1 = amplitude of lunar diurnal constituent,

M_2 = amplitude of principal lunar semidiurnal constituent,

and

S_2 = amplitude of principal solar semidiurnal constituent.

Each year the earth and sun revolve around their common center of mass in a plane called the ecliptic. Each month the moon and earth revolve around their common center of mass in a plane inclined about 5° to the ecliptic. Since the earth is tipped about 23-1/2° to the ecliptic, the

moon's orbit will always be inclined somewhat to the equatorial plane (obliquity of the moon's orbit) of the earth. Thus, the moon will have an apparent motion both north and south of the equator every month. The north and south excursion is known as lunar declination and is largely responsible for the "time" transition in type of tide from semidiurnal to mixed to diurnal. This is because the tide generating forces become further from a symmetrical orientation about the equator during these two periods every month. Since we rotate each day parallel to the plane of the equator, we experience these unsymmetrical tide generating forces which cause more and more diurnal inequality with greater and greater declination until, in extreme, diurnal tides may finally result.

The declinational effect is shown in figure 5 for Blackburn Point, Florida. (See figure 1 for location.) The moon's maximum north declination occurred on April 16th and its maximum south, on April 1st and 28th. On the 2nd through the 5th, and the 17th and 18th, the mixed tide went diurnal. The opposite extreme is shown in figure 4 for Pensacola, Florida. (See figure 1 for location.) The moon was over the equator on April 9 and 22, 1975.

On, and just before, these dates of minimum declination, the diurnal tide went semidiurnal.

Because the plane of the moon's orbit pivots on the ecliptic, the moon's maximum declination will occur alternately in and out of phase with the direction of the earth's inclination to the ecliptic. This pivoting, known as the regression of the moon's nodes, is westward and takes 18.61 years to complete. The consequence is that the semimonthly declination of the moon will vary from 28-1/2° (23-1/2° + 5°) to 18-1/2° (23-1/2° - 5°) and back again over the 18.61-year period. Reckoning convention is such that when the longitude of the moon's ascending node is zero (at the vernal equinox), maximum declinations are experienced, while at 180° minimum declinations occur.

The nodal effect is illustrated by comparing figure 6 with figure 7. Figure 6 is of a mixed tide (by quantitative definition) at Cedar Key, Florida, when the longitude of the moon's node is zero degrees. As seen, the tide goes diurnal. For the same station at 180°, the tide remains

mixed (figure 7). Additional mixed tide examples from other areas of the Gulf when the moon's node is zero degrees are given in figures 10 and 11.

Figures 8 and 9 are of a diurnal tide (by quantitative definition) at St. Petersburg, Florida. At zero degrees the diurnal aspect is dominant while at 180° the tide has become almost exclusively mixed.

The sun is an additional, although smaller, tide producing body. Since the earth is tipped about 23-1/2° to the ecliptic, a maximum solar declinational effect will be experienced at the beginning of both winter and summer.

In summary, the maximum declinational effect (i.e., the tendency of a tide to have greater diurnal inequality and finally become diurnal) would occur:

A. At the maximum semimonthly declination of the moon north and south of the equator,

B. when the longitude of the moon's ascending node is zero degrees, and

C. at the beginning of winter or summer when the sun is at its maximum declination.

Conversely, the tendency of a diurnal tide to become mixed and to have less diurnal inequality would occur:

A. Semimonthly as the moon passes over the equator,

B. when the longitude of the moon's ascending node is 180°, and

C. at the beginning of spring or fall when the sun is over the equator.

Because of bottom friction, viscosity, presence of continents, irregular oceanic basins, nonuniform depths, reflections, and interferences, certain oceanic regions tend to <u>respond</u> differently to the tide generating forces.

Areas of the Gulf of Mexico happen to be particularly sensitive to diurnal tendencies, giving rise to areas with predominantly mixed and diurnal tides.

III. TIDAL DATUMS

A datum is a reference base from which measurements are made. A vertical datum is, as the name implies, a reference base from which elevations and depths are measured. A tidal datum is a vertical datum defined in terms of an observed tidal phenomenon. Although there are many tidal datums, this report is only concerned with two: mean low water and mean lower low water. A third will be proposed in "V. CONCLUSIONS."

Mean low water is defined as:

The arithmetic mean of the low water heights observed over a specific 19-year Metonic cycle (the National Tidal Datum Epoch). For stations with shorter series, simultaneous observational comparisons are made with a primary control tide station in order to derive the equivalent of a 19-year value. Use of the synonymous term, mean low tide, is discouraged.

For a semidiurnal or mixed tide, the two low waters of each tidal day are included in the mean. When any

higher low water is indistinct, it is determined by record examination (figure 5). For a diurnal tide, the one low water of each tidal day is used in the mean. In the event a second low water occurs, only the diurnal low water is included (figure 4). So determined, this mean low water, based on the diurnal tide, is the equivalent of mean lower low water of a mixed tide.

Mean lower low water is:

The arithmetic mean of the lower low water heights of a mixed tide observed over a specific 19-year Metonic cycle (the National Tidal Datum Epoch). Only the lower low water of each pair of low waters of a tidal day is included in the mean. For stations with shorter series, simultaneous observational comparisons are made with a primary control tide station in order to derive the equivalent of a 19-year value.

A 19-year Metonic cycle is used in order to include all possibly significant tidal cycles through the 18.6-year period for the regression of the moon's nodes (node cycle)

while still terminating on a complete yearly (much larger) cycle. As there are irregular (in time and space) apparent secular trends in sea level (figure 12), a specific 19-year cycle (the National Tidal Datum Epoch) is necessary so that all tidal datum determinations throughout the United States will have a common reference. The National Tidal Datum Epoch officially adopted by the National Ocean Survey is 1941 through 1959. The Epoch will be reviewed for possible revision at 25-year intervals. As seen, tidal datums are defined in terms of a method designed to mathematically "fix" the vertical oscillations of the sea relative to the land.

Mean low water or mean lower low water is used (in different areas) as Chart Datum for the United States. That is, they are used as the base from which the printed depths and contours on nautical charts and bathymetric maps are referred. In addition, they are used as the base elevation of the water surface for its intersection with the land to form the depiction of the low water line on large-scale charts. Further, they are used as the base from which tide predictions are referred.

In addition to Chart Datum, these datums are used for *in situ* positioning of the low water and lower low water lines as boundaries, lines from which boundaries are measured, and/or points for the construction of boundary base lines.

IV. THE GULF COAST PROBLEM

Along the West Coast of the United States the type of tide is mixed and Chart Datum is mean lower low water. Along the East Coast the type of tide is semidiurnal and Chart Datum is mean low water.

However, along the Gulf Coast of the United States the tide is mixed in some areas and diurnal in others. Essentially, it is mixed from Key Largo to Apalachicola with diurnal tides in the Tampa Bay and Charlotte Harbor areas. It is chiefly diurnal from Apalachicola to the Rio Grande, except for the Sabine and Calcasieu Passes areas where it is mixed (figure 1). In addition to these generalizations, there are many others associated with islands, distances up bays and estuaries, and within lagoons (figure 2).

Figure 13, a simplified, idealistic, schematic representation of a region of the Gulf Coast, shows the change in the type of tide with distance along the coast and its marked effect on tidal datums.

At section 1 of figure 13, the tide is mixed with a definite higher high water, lower high water, higher low water, and lower low water. As one moves down the beach to section 4, the tide remains mixed but exhibits more and more diurnal inequality. That is, the lower highs become lower and the higher lows become higher until a platform finally occurs at section 5. Past section 5, however, the tide has become diurnal with perfect symmetry finally achieved in section 7.

The datum of mean low water (MLW) has been sketched in on each section and extended to intersect the beach. Note that there is a distinct drop in MLW immediately after section 5. The intersections of MLW with the beach are connected to form the mean low water line (MLWL). Also note the drop and seaward jump in the MLWL immediately after section 5.

As the tide goes from mixed to diurnal (sections 1 to 7), the lower highs and higher lows meld out of existence (section 5) at midelevation rather than at the elevations of higher high and/or lower low water. In this case,

the MLWL of the mixed tide does not fade into the MLWL of the diurnal tide. There is an abrupt discontinuity in elevation and horizontal position on the beach. Furthermore, the abrupt discontinuity becomes greater and greater the closer and closer the transition point (section 5) is approached!

Similarly, the datum of mean lower low water (MLLW) has been sketched in on each mixed tide section (sections 1 to 5) and extended to intersect the beach. These intersections are connected to form the mean lower low water line (MLLWL). Note that the MLLWL of the mixed tide continues in analogous tidal concept and elevation as the MLWL of the diurnal tide with no discontinuities in elevation or horizontal position on the beach!

Chart Datum in those areas of the Gulf where the tide is diurnal is mean low water. For those areas of the Gulf where the tide is mixed, Chart Datum is mean low water in some parts and mean lower low water in others.

But, whatever Chart Datum actually _is_ along the Gulf, it is always _called_ mean low water. This practice gives rise to two discrepancies: one in concept and elevation and one in name.

The concept and elevation discrepancy is that mean lower low water (not mean low water) of a mixed tide is analogous to mean low water of a diurnal tide. This can easily be seen in figure 5. When a mixed tide goes diurnal with time, it is because the moon is at or near its maximum semimonthly declination north or south of the equator (compounded by solar declination and nodal effects, as described before). This accentuates the diurnal portion of the total tide until the diurnal dominates the signature. The mixed lower lows are analogous to the diurnal lows in both concept and elevation with time as well as with distance (as previously described).

The name discrepancy is that mean lower low water has, in some cases, been called mean low water for the sake of name unity along the entire Gulf. This decision was

unfortunate because there is a <u>real</u> mean low water in a mixed tide and it is at an entirely different (higher) elevation. Also (as described before), mean low water of a diurnal tide is a different name than its counterpart (in concept and elevation) in a mixed tide. Thus, there exists a confusion in names.

The two discrepancies are summarized schematically in figure 14.

V. CONCLUSIONS

A. There should be one, common, continuous, reference base (composed of one or more tidal datums) for Chart Datum and for coastal boundary determinations throughout the coastal waters of the Gulf of Mexico.

B. The only reference that could provide a common, continuous Chart Datum and coastal boundary base along the entire Gulf Coast is mean lower low water when the type of tide is mixed and mean low water when the type of tide is diurnal.

C. Chart Datum for the Gulf should have one name. This name should not duplicate an existing tidal datum name if the datums are at different elevations.

VI. RECOMMENDATIONS

It is recommended that:

A. A new datum, called Gulf Coast Low Water Datum, be established by the National Ocean Survey;

B. Gulf Coast Low Water Datum be defined as mean lower low water when the type of tide is mixed and mean low water when the type of tide is diurnal;

C. Gulf Coast Low Water Datum be designated as Chart Datum for the coastal waters of the Gulf Coast of the United States;

D. the datum statements be changed from mean low water to Gulf Coast Low Water Datum and the relatively few necessary adjustments be made in the Tide Tables with the next regularly scheduled preparation cycle;

E. the datum statements on the archived smooth sheets and Descriptive Reports of hydrographic and certain

topographic surveys be changed to explain their original datum and its relationship to Gulf Coast Low Water Datum on release;

F. the datum statements on all nautical charts and bathymetric maps be changed from mean low water to Gulf Coast Low Water Datum with the next regularly scheduled New Edition or New Print (revision);

G. nautical charts and bathymetric maps covering areas where both Chart Datum of the Atlantic Coast (mean low water) and Chart Datum of the Gulf Coast (Gulf Coast Low Water Datum) occur on the same chart or map, have the areas separated by line segments (shown in figure 15) and prominently labeled on the next regularly scheduled New Edition or New Print (revision);

H. the line segments separating Chart Datum of the Atlantic Coast from Chart Datum of the Gulf Coast (shown in figures 15 and 16) extend --

1. from the intersection of the most westerly segment of the southern border of Biscayne National Monument and the land (just south of Mangrove Point),

2. along the southwest segments of the border of the Monument to Old Rhodes Point on the southeast corner of Old Rhodes Key,

3. hence, from Old Rhodes Point to the northwest corner of the John Pennekamp Coral Reef State Park,

4. along the land of the western border of the Park (with the exception of the coastal indentations of Largo Sound) to the southwest corner (just southwest of Rock Harbor), and

5. hence, from the southwest corner of the John Pennekamp Coral Reef State Park along its southwest border and continuing straight out to sea just south and beyond Molasses Reef;

I. new hydrographic and coastal mapping surveys, and their resulting nautical charts and bathymetric maps, be based on Gulf Coast Low Water Datum; and

J. a vigorous hydrographic and coastal mapping program already begun be accelerated along the west coast of Florida as soon as possible.

VII. IMPACTS OF RECOMMENDATIONS

Adoption of Gulf Coast Low Water Datum will entail the following:

A. Key West and approximately 43 subordinate tide stations will probably have to be adjusted to Gulf Coast Low Water Datum (GCLWD). The remaining Gulf stations will not have to be adjusted to the new datum. They are already referenced to the equivalent of GCLWD. Datum statements for all United States stations in the Gulf of Mexico, constants and ranges for the subordinate stations, and predictions for Key West in the publication, "Tide Tables, East Coast of North and South America, Including Greenland," will have to be changed accordingly with the next regularly scheduled preparation cycle.

B. The datum statements on all hydrographic surveys of waters of the Gulf of Mexico whose depths are referenced to mean lower low water (MLLW) of the mixed tide or mean low water (MLW) of the diurnal will have to have the statements changed on the archived smooth sheets and in the Descriptive Reports from MLLW or MLW (of the diurnal

tide) to GCLWD as released. There are approximately 462 surveys in this category. The datum statments on approximately 60 topographic survey sheets of the "Low Waterline Surveys of the Louisiana Coast" will have to be changed from MLW to GCLWD as released.

C. The datum statements on all nautical charts and bathymetric maps of waters of the Gulf of Mexico whose depths are referenced to MLLW of the mixed tide or MLW of the diurnal will have to have the statements changed from MLW to GCLWD with the next regularly scheduled New Edition or New Print (revision). There are about 82 nautical charts and bathymetric maps in this category.

D. The datum statements on all nautical charts and bathymetric maps of waters of the Gulf of Mexico whose depths are referenced to MLW of the mixed tide (west coast of Florida) will have to have the statements changed from MLW to GCLWD with the next regularly scheduled New Edition or New Print (revision). There are about 43 nautical charts in this category. Justification for this action is based on:

1. The inherent inaccuracies (by present sounding and navigational standards) of the very old hydrographic surveys from which well over 90% of the present nautical charts are comprised (e.g., 210 surveys prior to 1938; 10 since 1964);

2. very localized theoretical discrepancy maxima of 0.6 foot;

3. roundoff computations of soundings from field measurements to published charts; and

4. shoaling, deposition, erosion, and accretion amounting to far more than 2. and 3. (above), especially in view of 1.

E. The following nautical charts, covering areas where both Chart Datum of the Atlantic Coast and Chart Datum of the Gulf Coast occur on the same chart, will have to have the two datum areas separated by line segments and prominently labeled with the next regularly scheduled New Edition or New Print (revision):

411	(1007)	Gulf of Mexico
11013	(1002)	Straits of Florida and approaches
11451	(141-SC)	Miami to Marathon and Florida Bay
11460	(1112)	Cape Canaveral to Key West
11462	(1249)	Fowey Rocks to Alligator Reef
11463	(849)	Elliott Key to Tarpon Basin
11463	(850)	Tarpon Basin to Matecumbe

F. The changeover to GCLWD would not be fully implemented until new hydrographic surveys are completed for all of the waters now actually referenced to MLW of the mixed tide. There are approximately 300 surveys and about 43 charts in this category. They are located from Apalachicola around to Biscayne Bay on the west coast of Florida. The task of attempting to go back and revise soundings and depth curves, particularly the low water line, on completed surveys would be prohibitive, even with computer support. This includes data in the Marine Data Systems Project.

G. Appropriate changes will have to be made in the Nautical Chart Manual; Hydrographic Manual; Tide and

Current Glossary; Nautical Chart Symbols and Abbreviations; Topographic Manual, Part II; appropriate Photogrammetric Instructions; et cetera.

H. There will be no impact on the mariner. Marine safety factors will not be increased or decreased. Only the chart datum name will be changed (from MLW to GCLWD) on nautical charts and bathymetric maps and in the Tide Tables and related publications such as the Coast Pilot series, et cetera.

I. New hydrographic and coastal mapping surveys on the west coast of Florida may theoretically move any low water coastal boundaries seaward several feet to the advantage of the State. However, the change will be difficult to locate *in situ* and, in most cases, probably will be less than the thickness of the line depicting the boundary on large-scale charts.

J. A uniform, consistent, and logical (both technically and legally) base will be established for all charts and for State-Federal and Federal-International coastal boundary determinations.

VIII. DISCUSSION OF RECOMMENDATIONS

With respect to the Gulf, the quantitative classification system for type of tide is of limited importance. It is necessary to delineate the boundary between Chart Datum of the Atlantic Coast (mean low water of the semidiurnal tide) and Chart Datum of the Gulf Coast (Gulf Coast Low Water Datum [mean lower low water of the adjacent mixed tide]) when the two Chart Datums occur on the same nautical chart or bathymetric map.

The quantitative system is also used to determine whether mean high water (MHW) and mean higher high water (MHHW) of the mixed tide or just MHW of the diurnal can be provided for those locations near the transition between the mixed and diurnal types.

One of the main advantages of Gulf Coast Low Water Datum (GCLWD) is its independence (except in the above two instances) of changes in type of tide. If subsequent observations at closer distance intervals reveal that the "type of tide" separation lines on figures 1 and 2 should be

moved, it would make no difference to GCLWD or its derived coastal boundaries, since the lower lows and analogous single lows (present in both types) are the only ones used in the computations. This advantage does not exist with the present system.

Similarly, it would make no difference if a longer series of observations at a station revealed that a tide previously classified as mixed should now be classified as diurnal (or vice versa) or if the critical classification ratio value itself was changed. In either case, it is the lower lows and analogous single lows (possessed by both types) that would be used for the datum computations -- a distinct advantage of the new system over the present one.

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APPENDIX A. PROPOSED TIDAL DATUM POLICY FOR THE GULF COAST OF THE UNITED STATES

Since the type of tide containing one high water (and one low water) and the type containing two high waters (and two low waters) each tidal day, as observed along the Gulf Coast of the United States, often vary from place to place and in time; and since it is essential in accurate and consistent surveying, charting, mapping, and tide prediction practices to have:

1. Continuous, uninterrupted tidal datums (i.e., without numerous, abrupt, vertical jumps);

2. continuous, uninterrupted, coastal boundaries (i.e., without numerous, abrupt, horizontal discontinuities) along geographically unified coastlines; and

3. a uniform Chart Datum common to all nautical charts, bathymetric maps, and tide tables of a geographically unified oceanic area;

therefore, it shall be the policy of the National Ocean Survey to apply the following conventions and definitions throughout the entire Gulf Coast of the United States:

1. Gulf Coast Low Water Datum will be used by the National Ocean Survey as Chart Datum for the coastal waters of the Gulf Coast of the United States.

2. Gulf Coast Low Water Datum is defined as: *mean lower low water* when the type of tide is *mixed* and *mean low water* when the type of tide is *diurnal*.

3. Tides will be classified according to the following nondimensional factor system (after Marmer, 1951):

$$R = \frac{K_1 + O_1}{M_2 \quad S_2}$$

TYPE	
Semidiurnal (Semidaily)	$R = < .25$
Mixed	$R = .25\text{-}1.50$
Diurnal (Daily)	$R = > 1.50$

where:

R = ratio

K_1 = amplitude of lunisolar diurnal constituent,

O_1 = amplitude of lunar diurnal constituent,

M_2 = amplitude of principal lunar semidiurnal constituent,

and

S_2 = amplitude of principal solar semidiurnal constituent.

4. The value, .25 (3. above), will be used to delineate the boundary between Chart Datum of the Atlantic Coast (*mean low water*) and Chart Datum of the Gulf Coast (Gulf Coast Low Water Datum) on nautical charts and bathymetric maps, and for tide predictions.

5. The nondimensional factor system (3. above) will be used to determine whether certain datums can be provided by the National Ocean Survey. If the value of the ratio is 1.50 or less, *mean higher high water, mean high water, mean low water, and mean lower low water* can be provided. If the value is greater than 1.50, *mean high water* and *mean low water* of the *diurnal* tide can be provided.

APPENDIX B. DEFINITIONS[1]

APPARENT SECULAR TREND - The nonperiodic tendency of sea level to rise, fall, and/or remain stationary with time. Technically, it is frequently defined as the slope of a least-squares line of regression through a relatively long series of yearly mean sea level values. The word "apparent" is used since it is often not possible to know whether a trend is truly nonperiodic or merely a segment of a very long (relative to the length of the series) oscillation.

BENCH MARK (BM) - A fixed physical object used as reference for a vertical datum. A *tidal bench mark* is one near a tide station to which the tide staff and tidal datums are referred. A *primary tidal bench mark* is the principal (or only) mark of a group of tidal bench marks to which the tide staff and tidal datums are referred. The standard tidal bench mark of the National Ocean Survey is a copper or aluminum alloy disk 3-1/2 inches in diameter containing the inscription "NATIONAL OCEAN SURVEY" together with other individual identifying information. A *geodetic bench mark* identifies a surveyed point in the National Geodetic Vertical Network. Geodetic bench mark disks contain the inscription "VERTICAL CONTROL MARK NATIONAL GEODETIC SURVEY" with other individual identifying information. Bench mark disks of either type may, on occasion, serve simultaneously to reference both tidal and geodetic datums. Numerous bench marks, both tidal and geodetic, still bear the inscription "U.S. COAST AND GEODETIC SURVEY."

CHART DATUM - The tidal datum to which soundings on a chart are referred. It is usually taken to correspond to a low water stage of the tide, and its depression below mean sea level is represented by the symbol Z_0. See also *datum*.

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[1] Schureman, P., 1975

COASTAL BOUNDARY - A general term for a boundary defined as the line (or measured from the line or points thereon) used to depict the intersection of the ocean surface and the land at an elevation of a particular datum.

COMPARISON OF SIMULTANEOUS OBSERVATIONS - A reduction process in which a short series of tide or tidal current observations at any place is compared with simultaneous observations at a control station where tidal or tidal current constants have previously been determined from a long series of observations. For tides, it is usually used to adjust constants from a subordinate station to the equivalent of that which would be obtained from a 19-year series.

CONSTITUENT - One of the harmonic elements in a mathematical expression for the tide-producing force and in corresponding formulas for the tide or tidal current. Each constituent represents a periodic change or variation in the relative positions of the earth, moon, and sun. A single constituent is usually written in the form $y=A\cos(at+\alpha)$, in which y is a function of time as expressed by the symbol t and is reckoned from a specific origin. The coefficient A is called the *amplitude* of the constituent and is a measure of its relative importance. The angle $(at+\alpha)$ changes uniformly and its value at any time is called the *phase* of the constituent. The *speed* of the constituent is the rate of change in its phase and is represented by the symbol $\underline{a}$ in the formula. The quantity α is the phase of the constituent at the initial instant from which the time is reckoned. The period of the constituent is the time required for the phase to change through 360° and is the cycle of the astronomical condition represented by the constituent. Further information on the harmonic constituents of the tide or tidal current will be found in Coast and Geodetic Survey Special Publication No. 98, *Manual of Harmonic Analysis and Prediction of Tides*.

DATUM (VERTICAL) - For marine applications, a base elevation used as a reference from which to reckon heights

or depths. It is called a *tidal datum* when defined by a certain phase of the tide. Tidal datums are local datums and should not be extended into areas which have differing topographic features without substantiating measurements. In order that they may be recovered when needed, such datums are referenced to fixed points known as *bench marks*. See *chart datum*.

DECLINATION - Angular distance north or south of the celestial equator, taken as positive (+) when north and negative (-) when south of the equator. The sun passes through its declinational cycle once a year, reaching its maximum north declination of approximately 23 1/2° about June 21 and its maximum south declination of approximately -23 1/2° about December 21. The moon has an average declinational cycle of 27 1/3 days which is called a *tropical month.* Tides or tidal currents occurring near the times of maximum north or south declination of the moon are called *tropic tides* or *tropic currents* and those occurring when the moon is over the equator are called *equatorial tides* or *equatorial currents.* The maximum declination reached by the moon in successive months depends upon the longitude of the moon's node, and varies from 28 1/2° when the longitude of the ascending node is zero to 18 1/2° when the longitude of the node is 180°. The node cycle or time required for the node to complete a circuit of 360° of longitude is approximately 18.6 years. See *epoch (2).*

DIURNAL - Having a period or cycle of approximately one tidal day. Thus, the tide is said to be diurnal when only one high water and one low water occur during a tidal day, and the tidal current is said to be diurnal when there is a single flood and single ebb period in the tidal day. A rotary current is diurnal if it changes its direction through all points of the compass once each tidal day. A diurnal constituent is one which has a single period in the constituent day. The symbol for such a constituent is usually distinguished by the subscript 1. See *type of tide.*

EPOCH - (2) As used in tidal datum determinations, it is a 19-year Metonic cycle over which tidal height observations are meaned in order to establish the various

datums. As there are periodic and apparent secular trends in sea level, a specific 19-year cycle (the National Tidal Datum Epoch) is selected so that all tidal datum determinations throughout the United States and its possessions will have a common reference. The National Tidal Datum Epoch officially adopted by the National Ocean Survey is 1941 through 1959. The National Tidal Datum Epoch will be reviewed for consideration for possible revision at 25-year intervals.

GULF COAST LOW WATER DATUM - Mean lower low water when the type of tide is mixed and mean low water when the type of tide is diurnal.

HIGH WATER (HW) - The maximum height reached by a rising tide. The height may be due solely to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Use of the synonymous term, *high tide*, is discouraged.

HIGHER HIGH WATER (HHW) - The higher of the two high waters of any tidal day.

HIGHER LOW WATER (HLW) - The higher of the two low waters of any tidal day.

K_1 - Lunisolar diurnal constituent. This constituent, with O_1, expresses the effect of the moon's declination. They account for diurnal inequality and, in extreme, diurnal tides. With P_1, it expresses the effect of the sun's declination.

LOW WATER (LW) - The minimum height reached by a falling tide. The height may be due solely to the periodic tidal forces or it may have superimposed upon it the effects of meteorological conditions. Use of the synonymous term, *low tide*, is discouraged.

LOW WATER LINE - The intersection of the land with the water surface at an elevation of low water.

LOWER HIGH WATER (LHW) - The lower of the two high waters of any tidal day.

LOWER LOW WATER (LLW) - The lower of the two low waters of any tidal day.

LUNAR DAY - The time of the rotation of the earth with respect to the moon, or the interval between two successive upper transits of the moon over the meridian of a place. The mean lunar day is approximately 24.84 solar hours in length, or 1.035 times as great at the mean solar day.

M_2 - Principal lunar semidiurnal constituent. This constituent represents the rotation of the earth with respect to the moon.

MEAN LOW WATER (MLW) - A tidal datum. The arithmetic mean of the low water heights observed over a specific 19-year Metonic cycle (the National Tidal Datum Epoch). See *epoch (2)*. For stations with shorter series, simultaneous observational comparisons are made with a primary control tide station in order to derive the equivalent of a 19-year value. Use of the synonymous term, *mean low tide*, is discouraged.

For a semidiurnal or mixed tide, the two low waters of each tidal day are included in the mean. When any higher low water is indistinct, it is determined by record examination. For a diurnal tide, the one low water of each tidal day is used in the mean. In the event a second low water occurs, only the diurnal low water is included (see *diurnal*). So determined, this mean low water, based on the diurnal tide, is the equivalent of mean lower low water of a mixed tide. See *datum* and *type of tide*.

MEAN LOWER LOW WATER (MLLW) - A tidal datum. The arithmetic mean of the lower low water heights of a mixed tide observed over a specific 19-year Metonic cycle (the National Tidal Datum Epoch). See *epoch (2)*. Only the lower low water of each pair of low waters of a tidal day is included in the mean. For stations with shorter series, simultaneous observational comparisons are made with a primary control tide station in order to derive the equivalent of a 19-year value. See *datum* and *type of tide*.

METONIC CYCLE - A period of 19 years or 235 lunations. Devised by Meton, an Athenian astronomer who lived in the fifth century B.C., for the purpose of obtaining a period in which new and full moon would recur on the same day of year. Taking the Julian year of 365.25 days and the synodic month as 29.530588 days, we have the 19-year period of 6939.75 days as compared with the 235 lunations of 6939.69 days, a difference of only 0.06 day.

MIXED (TIDE) - Type of tide with a large inequality in either the high and/or low water heights, with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed but the name is usually applied to the tides intermediate to those predominantly semidiurnal and those predominantly diurnal. See *type of tide*.

NATIONAL TIDAL DATUM EPOCH - The specific 19-year cycle adopted by the National Ocean Survey as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of apparent periodic and apparent secular trends in sea level. The present National Tidal Datum Epoch is 1941 through 1959. It will be reviewed for possible revision every 25 years.

NODE CYCLE - Period of approximately 18.61 Julian years required for the regression of the moon's nodes to complete a circuit of 360° of longitude. It is accompanied by a corresponding cycle of changing inclination of the moon's orbit relative to the plane of the earth's equator, with resulting inequalities in the rise and fall of the tide and speed of the tidal current.

O_1 - Lunar diurnal constituent. See K_1.

PRIMARY CONTROL TIDE STATION - A tide station at which continuous observations have been made over a minimum of a 19-year Metonic cycle. Its purpose is to provide data for computing accepted values of the harmonic and nonharmonic constants essential to tide predictions and to the determination of tidal datums for charting and coastal

boundaries. The data series from this station serves as a primary control for the reduction of relatively short series from subordinate tide stations through the method of comparison of simultaneous observations, and for monitoring long-period sea-level trends and variations. See *tide station, subordinate tide station (1), secondary control tide station,* and *tertiary tide station.*

REFERENCE STATION - A tide or current station for which independent daily predictions are given in the *Tide Tables* and *Tidal Current Tables*, and from which corresponding predictions are obtained for subordinate stations by means of differences and ratios. See *subordinate tide station (2).*

S_2 - Principal solar semidiurnal constituent. This constituent represents the rotation of the earth with respect to the sun.

SECONDARY CONTROL TIDE STATION - A tide station at which continuous observations have been made over a minimum period of one year but less than a 19-year Metonic cycle. The series is reduced by comparison with simultaneous observations from a primary control tide station. This station provides for a 365-day harmonic analysis including the seasonal fluctuations of sea level. See *tide station, primary control tide station, subordinate tide station (1),* and *tertiary tide station.*

SEMIDIURNAL - Having a period or cycle of approximately one-half of a tidal day. The predominating type of tide throughout the world is semidiurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semidiurnal when there are two flood and two ebb periods each day. A semidiurnal constituent has two maxima and two minima each constituent day, and its symbol is usually distinguished by the subscript 2. See *type of tide.*

SEQUENCE OF TIDE - The order in which the four tides of a day occur, with special reference as to whether the higher high water immediately precedes or follows the lower low water.

SUBORDINATE TIDE STATION - (1) A tide station from which a relatively short series of observations is reduced by comparison with simultaneous observations from a tide station with a relatively long series of observations.

(2) A station listed in the *Tide Tables* for which predictions are to be obtained by means of differences and ratios applied to the full predictions at a reference station. See *primary control tide station, secondary control tide station, tertiary tide station,* and *reference station.*

TERTIARY TIDE STATION - A tide station at which continuous observations have been made over a minimum period of 30 days but less than one year. The series is reduced by comparison with simultaneous observations from a secondary control tide station. This station provides for a 29-day harmonic analysis. See *tide station, primary control tide station, subordinate tide station (1),* and *secondary control tide station.*

TIDAL DATUM - See *datum.*

TIDAL DAY - Same as *lunar day.*

TIDAL WAVE - A shallow water wave caused by the gravitational interactions between the sun, moon, and earth. Essentially, high water is the crest of a tidal wave and low water is the trough. Tide is the vertical component of the particulate motion and tidal current is the horizontal component. The observed tide and tidal current can be considered the result of the combination of several tidal waves, each of which may vary from nearly pure progressive to nearly pure standing and with differing periods, heights, phase relationships, and directions.

TIDE - The periodic rise and fall of the water resulting from gravitational interactions between the sun, moon, and earth. The vertical component of the particulate motion of a tidal wave. Although the accompanying horizontal movement of the water is part of the same phenomenon, it is preferable to designate this motion as *tidal current.* See *tidal wave.*

TIDE STATION - The geographic location at which tidal observations are conducted. Also, the facilities used to make tidal observations. These may include a tide house, tide gage, tide staff, and tidal bench marks. See *primary control tide station, subordinate tide station (1), secondary control tide station,* and *tertiary tide station.*

TYPE OF TIDE - A classification based on characteristic forms of a tide curve. Qualitatively, when the two high waters and two low waters of each tidal day are approximately equal in height, the tide is said to be *semidiurnal*; when there is a relatively large diurnal inequality in the high or low waters or both, it is said to be *mixed*; and when there is only one high water and one low water in each tidal day, it is said to be *diurnal.* Quantitatively (after Marmer and Van der Stok), where the ratio of $K_1 + O_1$ to $M_2 + S_2$ is less than 0.25, the tide is classified as *semidiurnal*; where the ratio is from 0.25 to 1.5, the tide is *mixed*; and where greater than 1.5, *diurnal.* The National Ocean Survey classifies tides quantitatively.

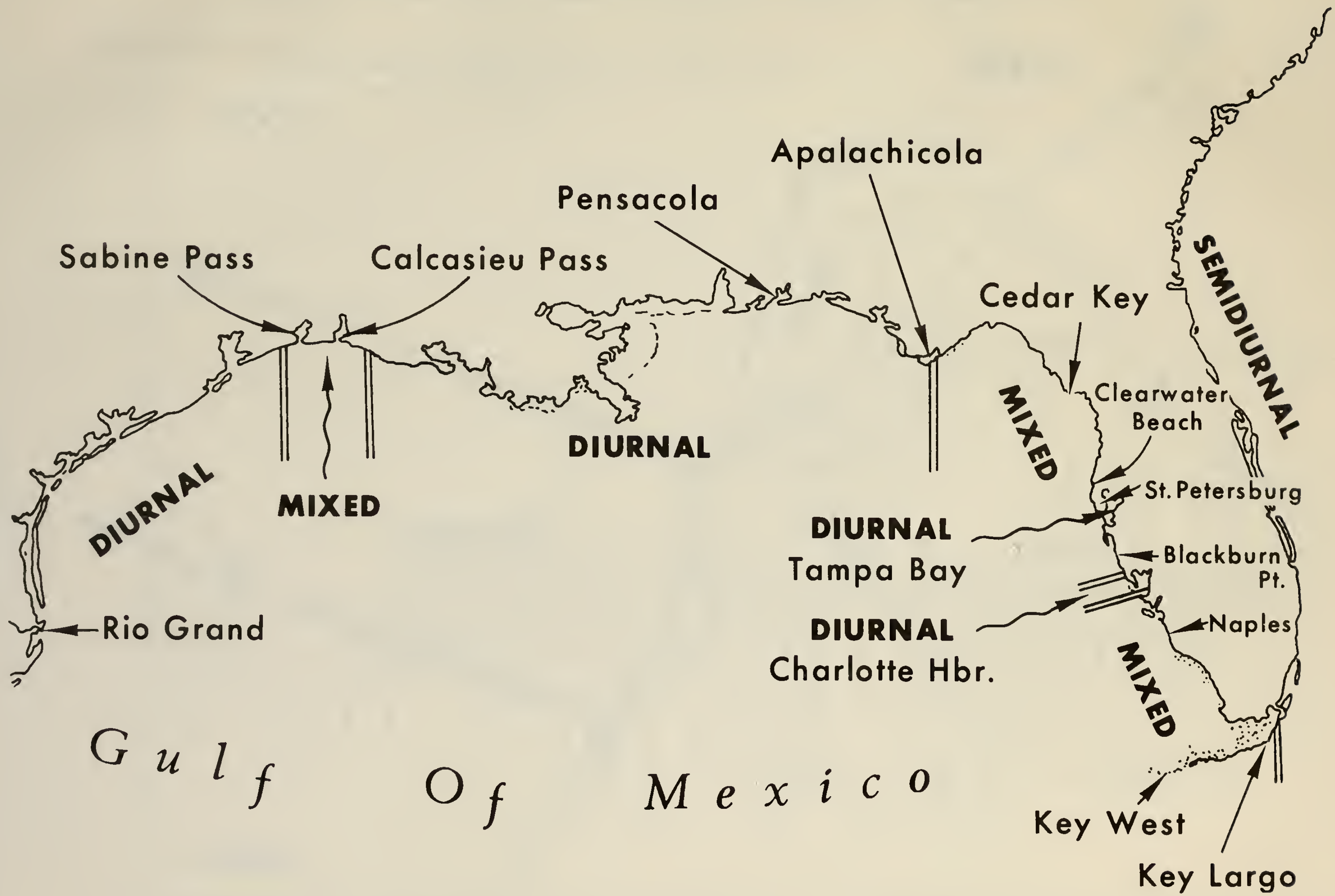


Figure 1.--Areal extent of tidal types and locations of stations with illustrated tide curves

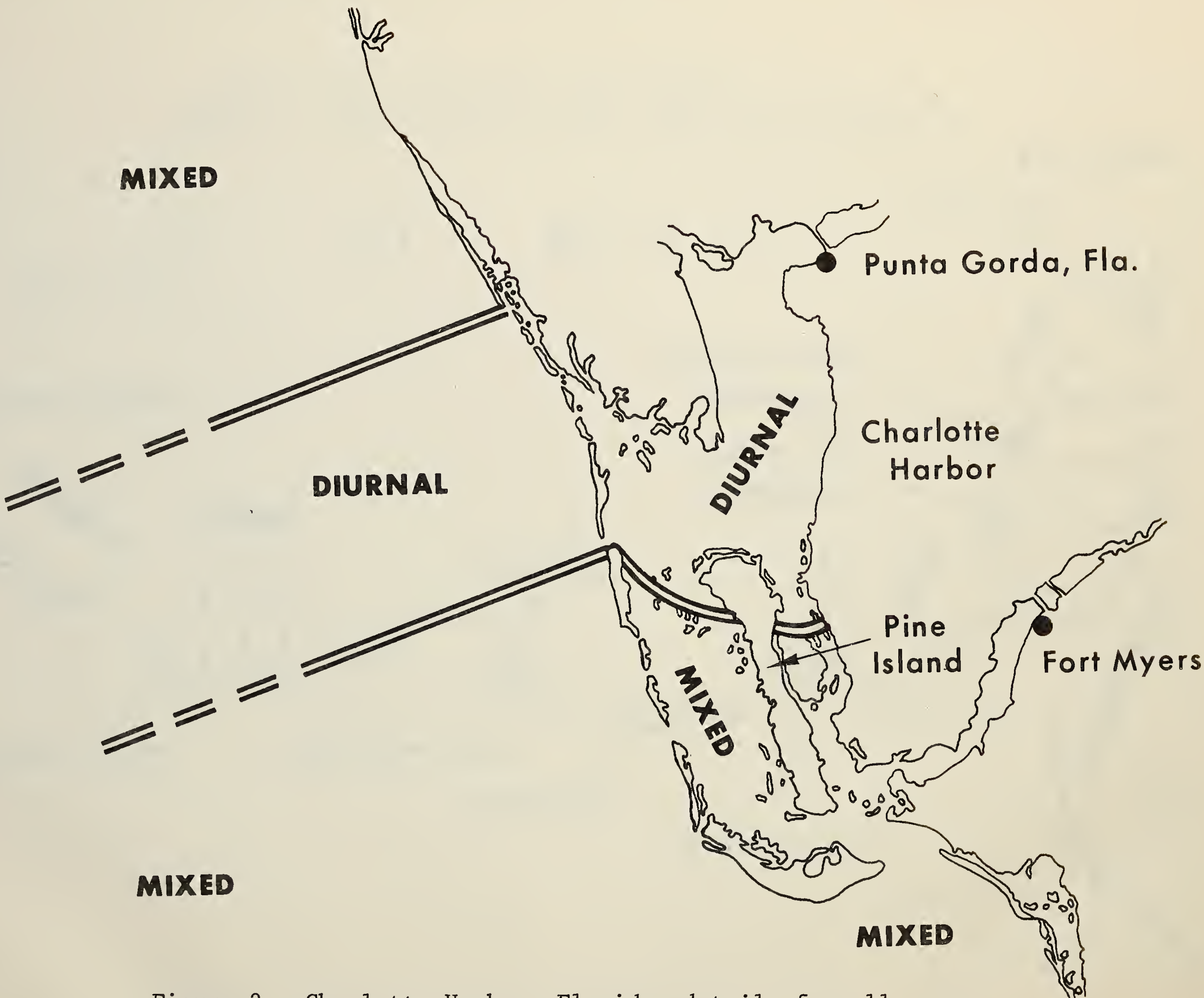


Figure 2.--Charlotte Harbor, Florida, detail of small area of Gulf Coast with several changes in tidal types

Figure 3.--EXAMPLE OF MIXED TIDE
CLEARWATER BEACH, FLORIDA APRIL 1975 RATIO = 0.89
PLOT OF HOURLY TIDAL HEIGHTS

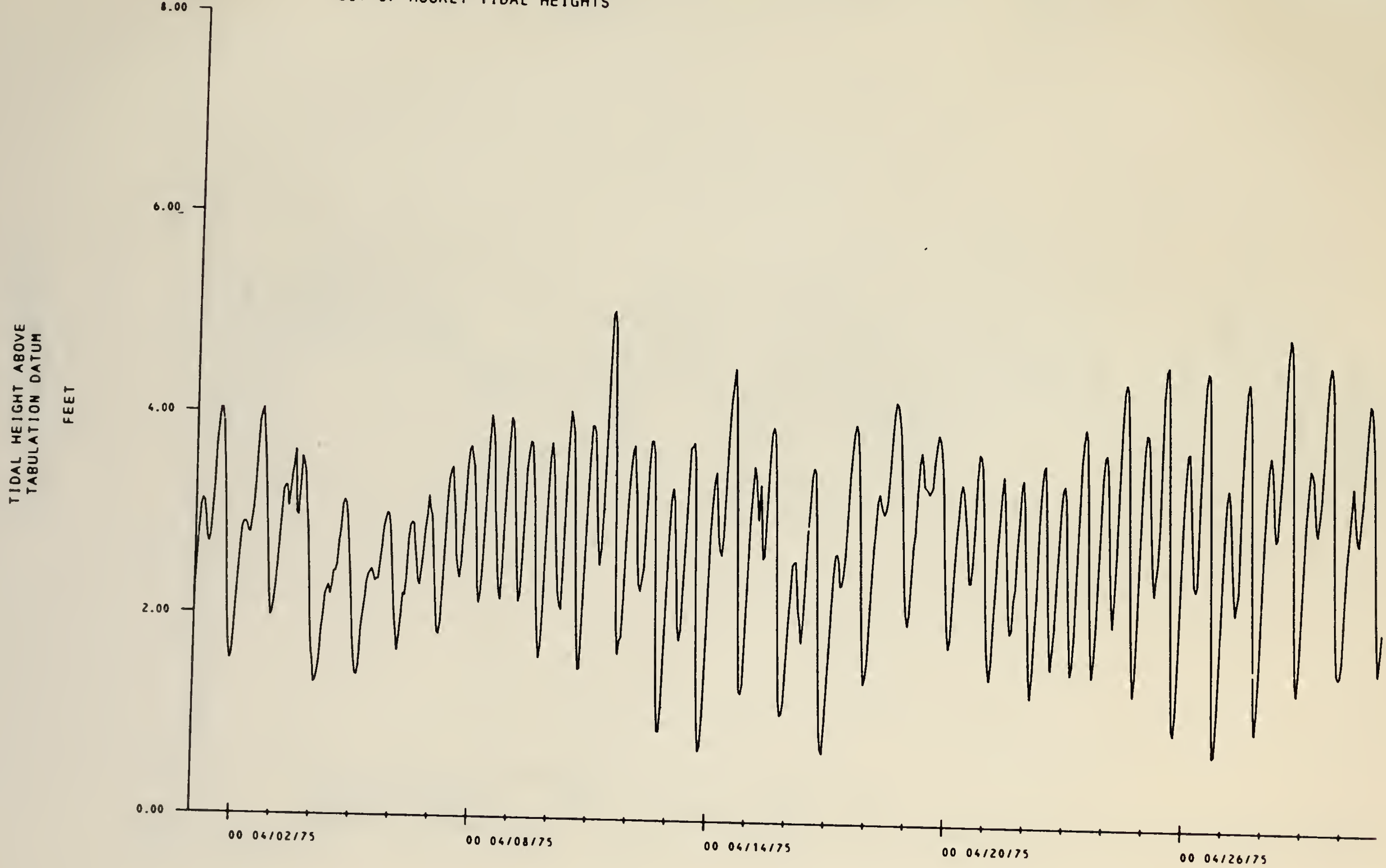


Figure 4.--EXAMPLE OF DIURNAL TIDE
PENSACOLA, FLORIDA APRIL 1 - 30, 1975 RATIO = 9.46
PLOT OF HOURLY TIDAL HEIGHTS

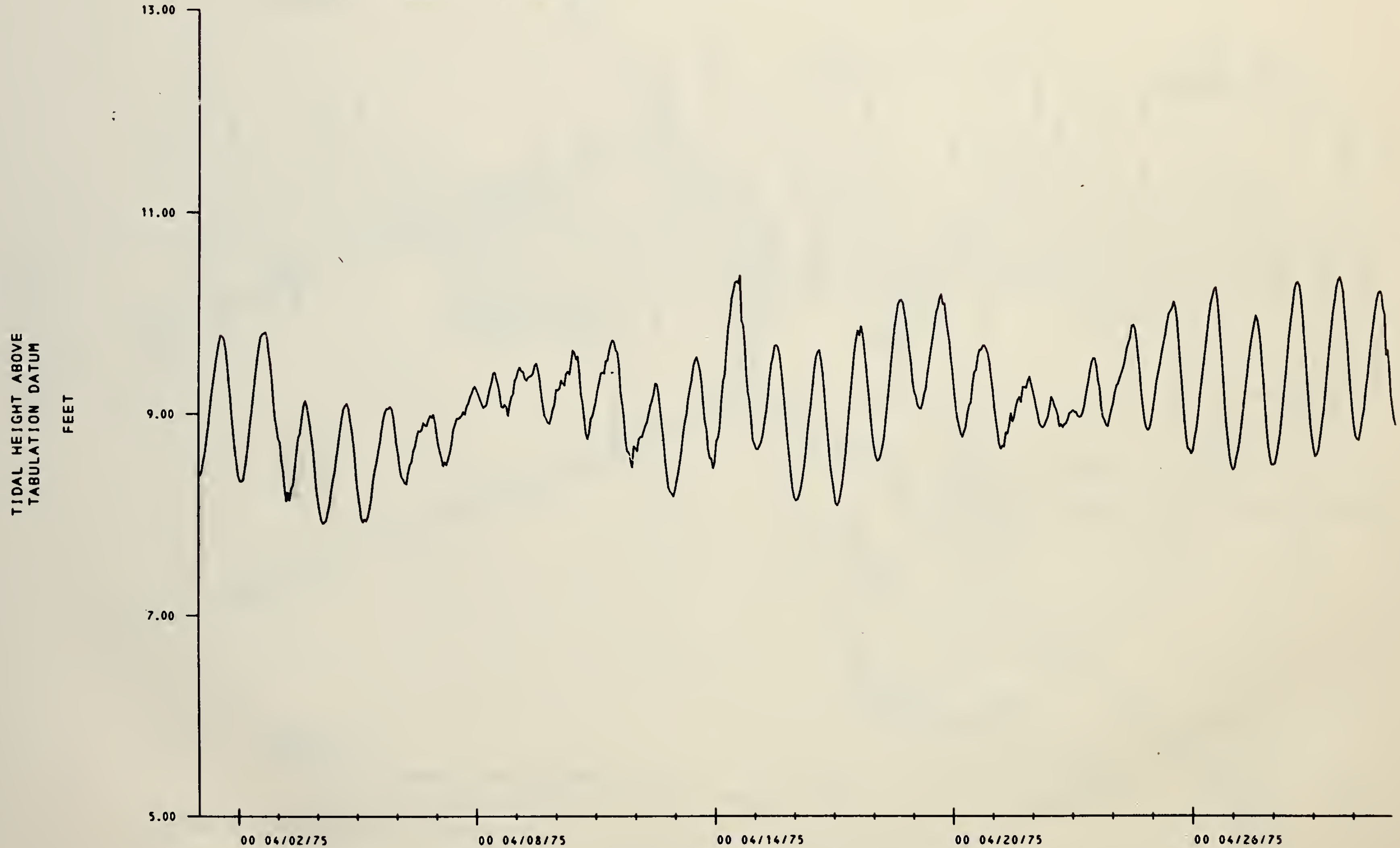


Figure 5.-- EXAMPLE OF MIXEO TIDE
BLACKBURN POINT, CASEY BAY, FLORIOA APRIL 1975 RATIO = 1.34
PLOT OF HOURLY TIDAL HEIGHTS

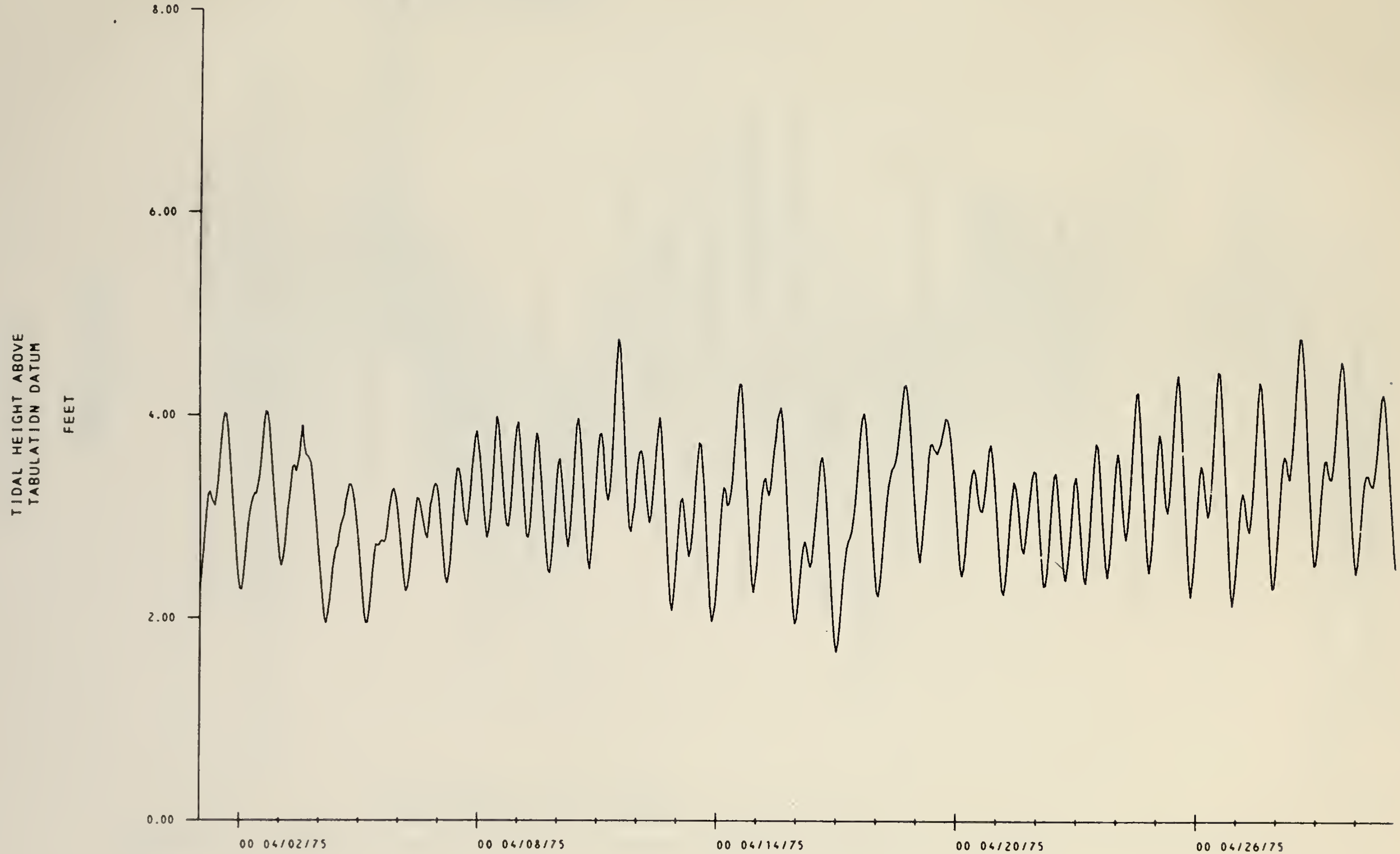


Figure 6.--EXAMPLE OF MIXED TYPE DF TIDE BECDMING DIURNAL WHEN LDNGITUDE DF MDDNS NDDE IS ZERO DEGREE
CEDAR KEY, FLDRIDA FEBRUARY 1969 RATID = 0.65
PLDT DF HDURLY TIDAL HEIGHTS

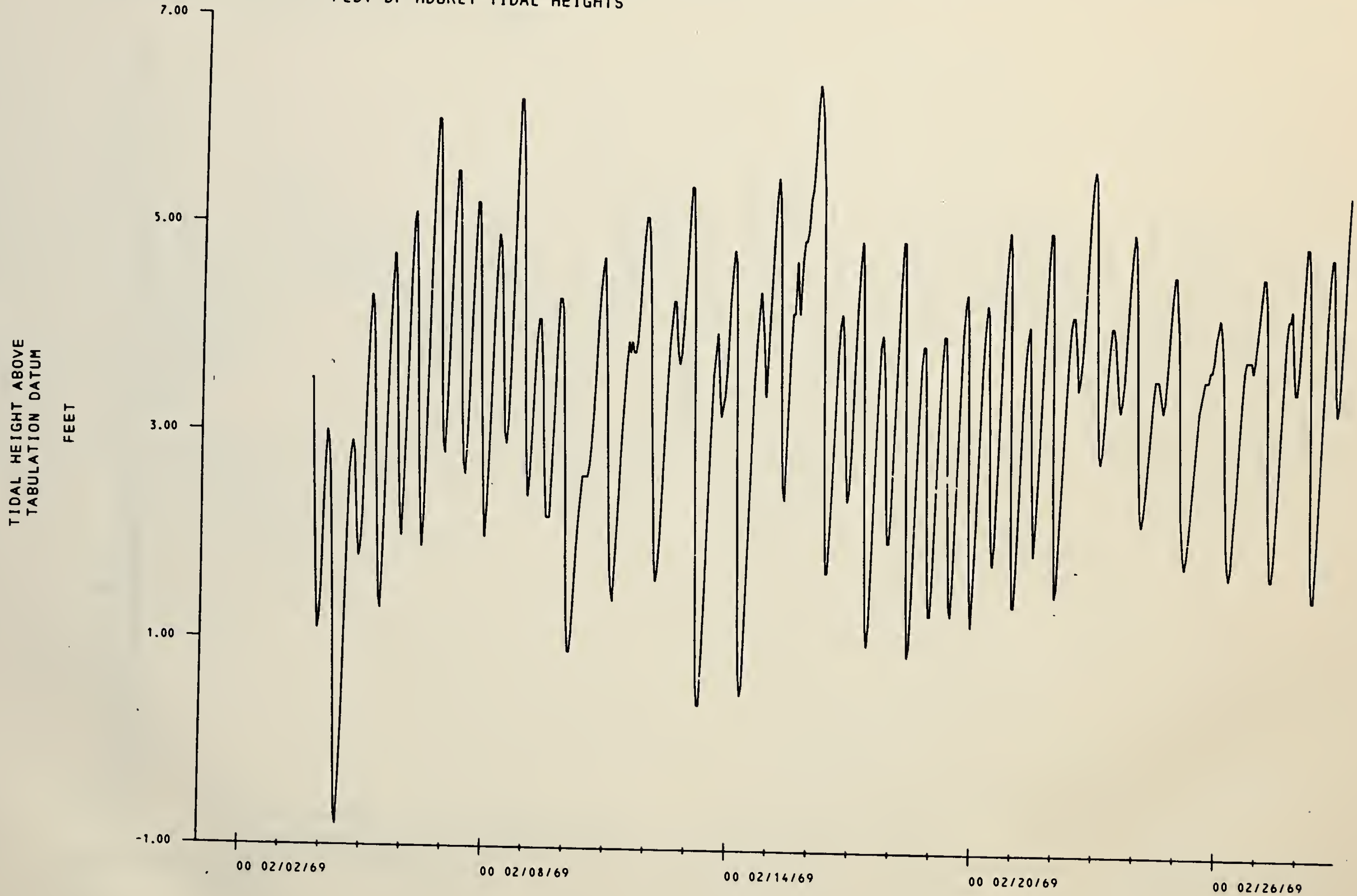


Figure 7.--EXAMPLE OF MIXED TYPE OF TIDE WHEN LONGITUDE OF MOONS NODE IS 180 DEGREES
CEDAR KEY, FLORIDA NOVEMBER 1959 RATIO = 0.65
PLOT OF HOURLY TIDAL HEIGHTS

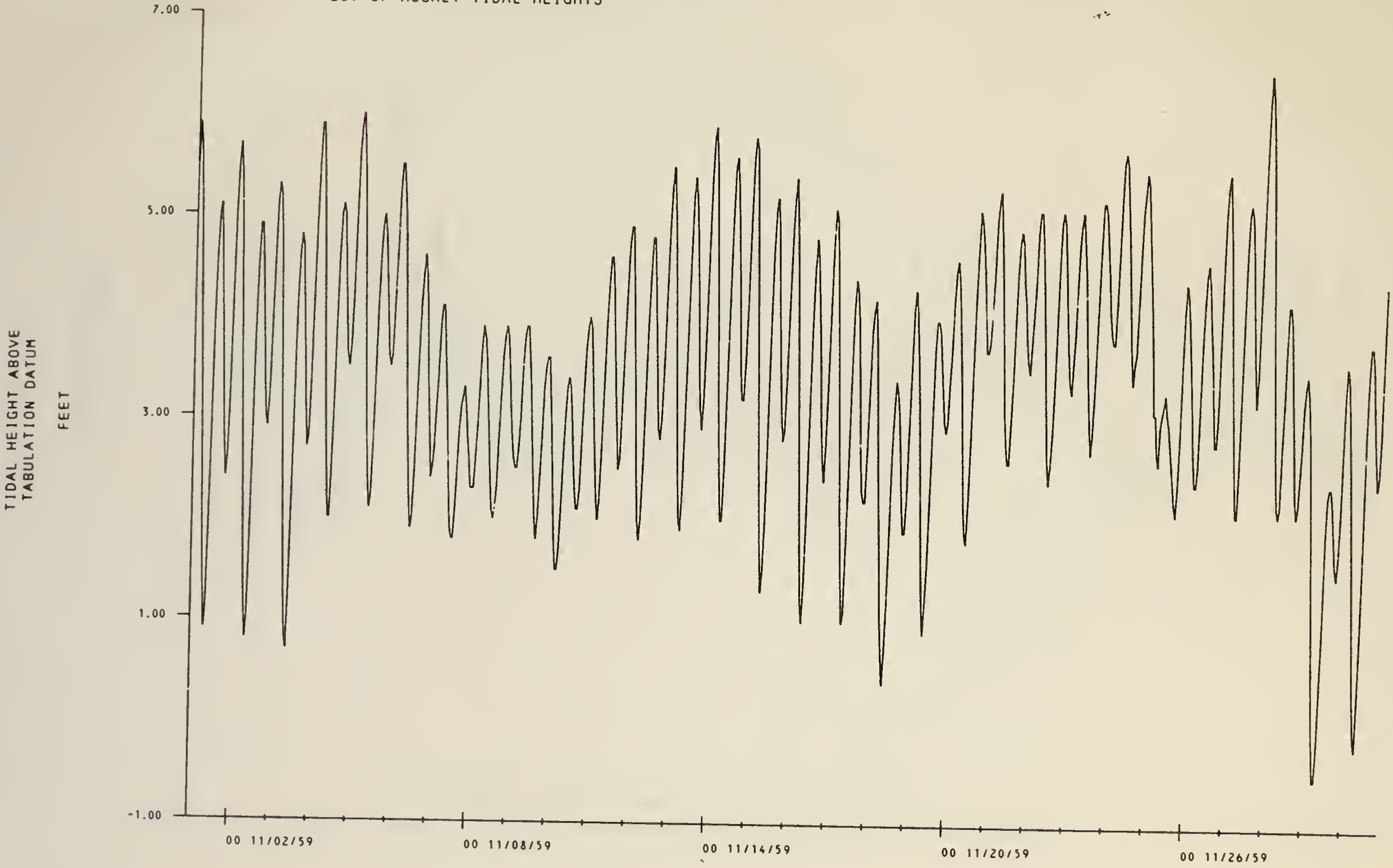


Figure 8.--EXAMPLE OF DIURNAL TYPE OF TIDE WHEN LONGITUDE OF MOONS NODE IS ZERO DEGREES
ST PETERSBURG, FLORIDA FEBRUARY 1969 RATIO = 1.509
PLOT OF HOURLY TIDAL HEIGHTS

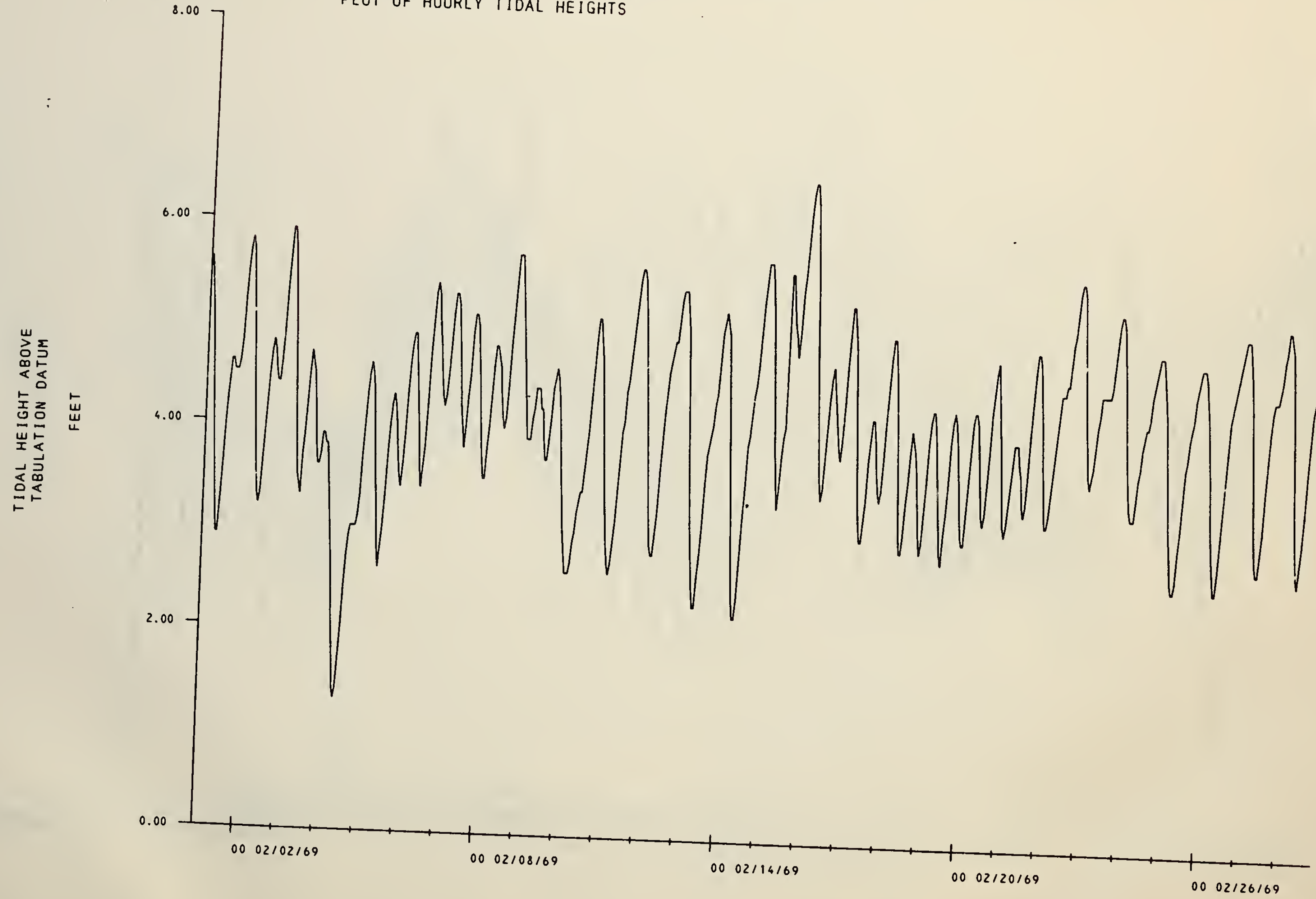


Figure 9.--EXAMPLE OF DIURNAL TYPE OF TIDE WHEN LONGITUDE OF MOONS NODE IS 180 DEGREES
ST PETERSBURG, FLORIDA NOVEMBER 1959 RATIO = 1.509
PLOT OF HOURLY TIDAL HEIGHTS

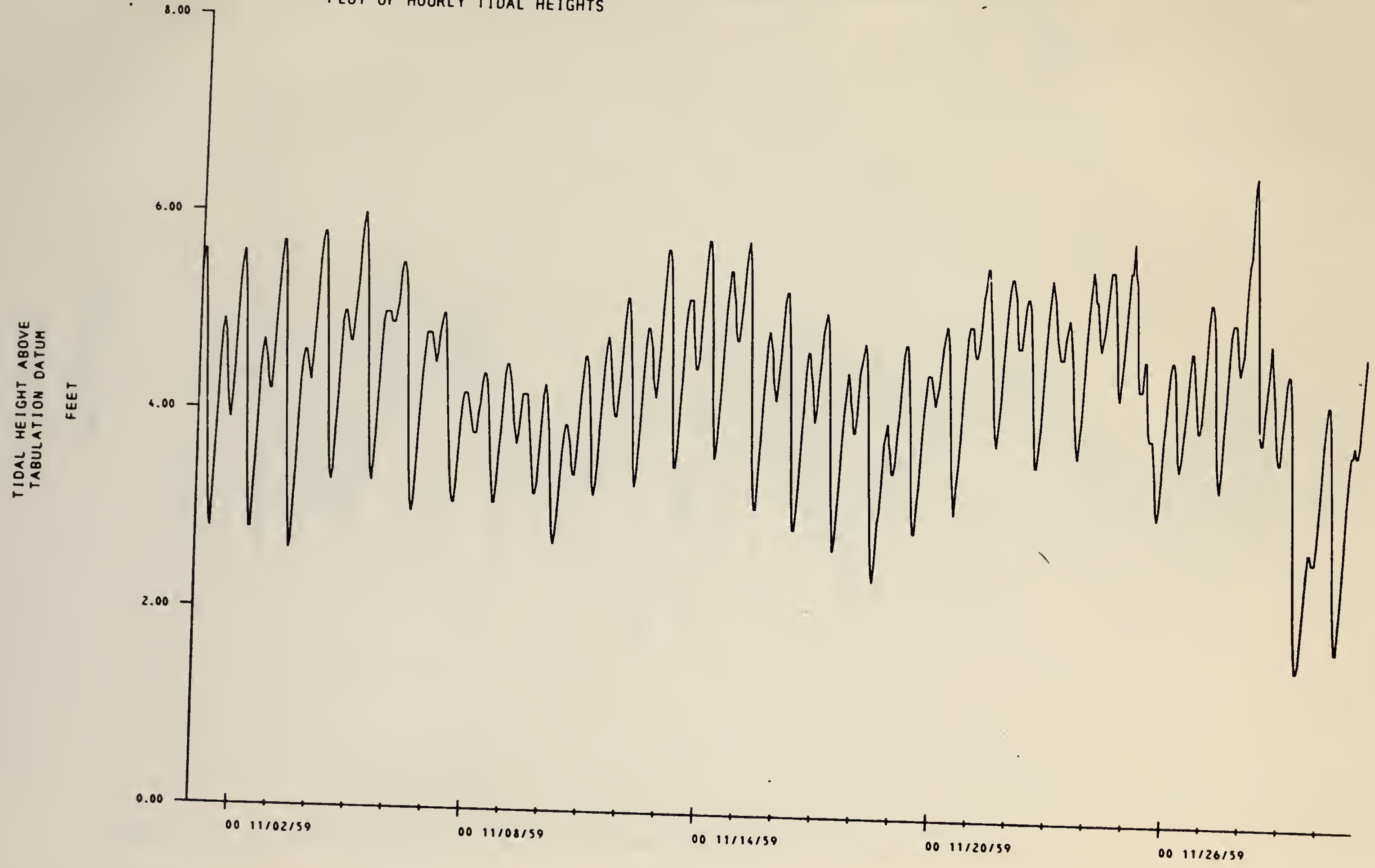
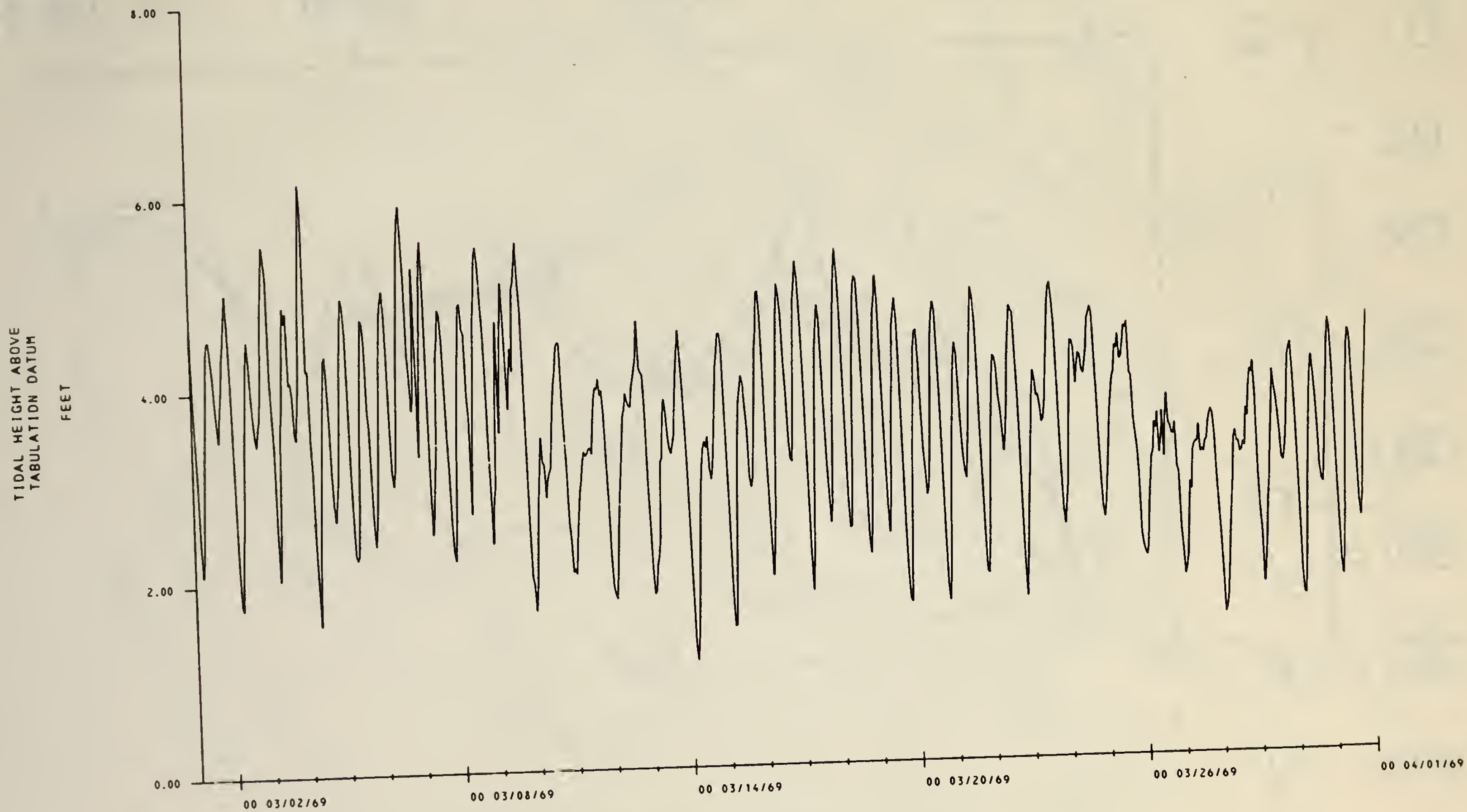


Figure 10.--EXAMPLE OF MIXED TYPE OF TIDE BECOMING DIURNAL WHEN LONGITUDE OF MOONS NODE IS ZERO DEGREE
FORT MYERS, FLORIDA FEBRUARY 1969 RATIO = 1.28
PLOT OF HOURLY TIDAL HEIGHTS

Figure 11.-- EXAMPLE OF MIXED TYPE OF TIOE BECOMING DIURNAL WHEN LONGITUDE OF MOONS NODE IS ZERO OEGREE
NAPLES, FLORIOA   MARCH 1969   RATIO = 0.77
PLOT OF HOURLY TIOAL HEIGHTS



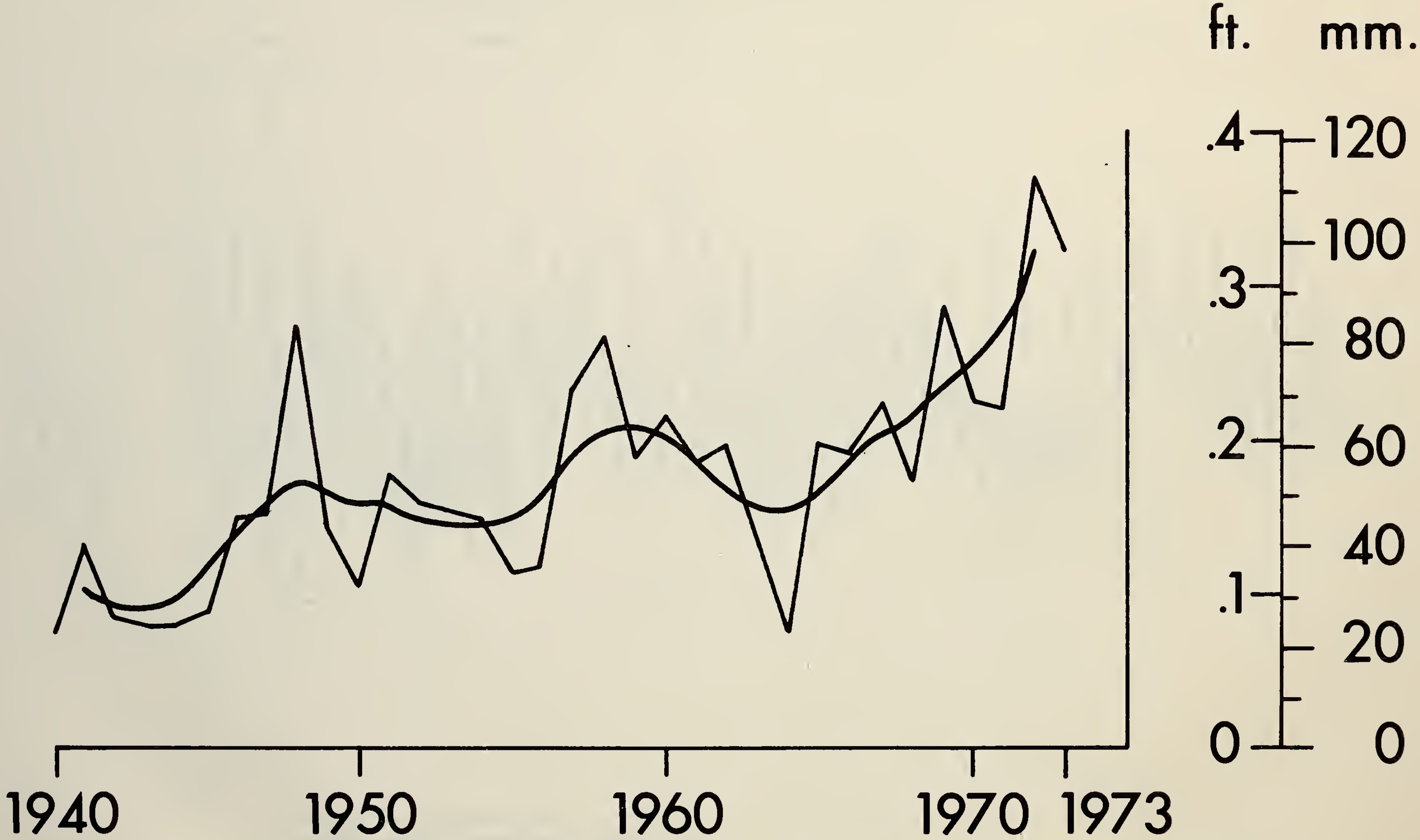


Figure 12.--Averaged sea-level series and curve for the United States (except Alaska and Hawaii) (Hicks and Crosby, 1975)

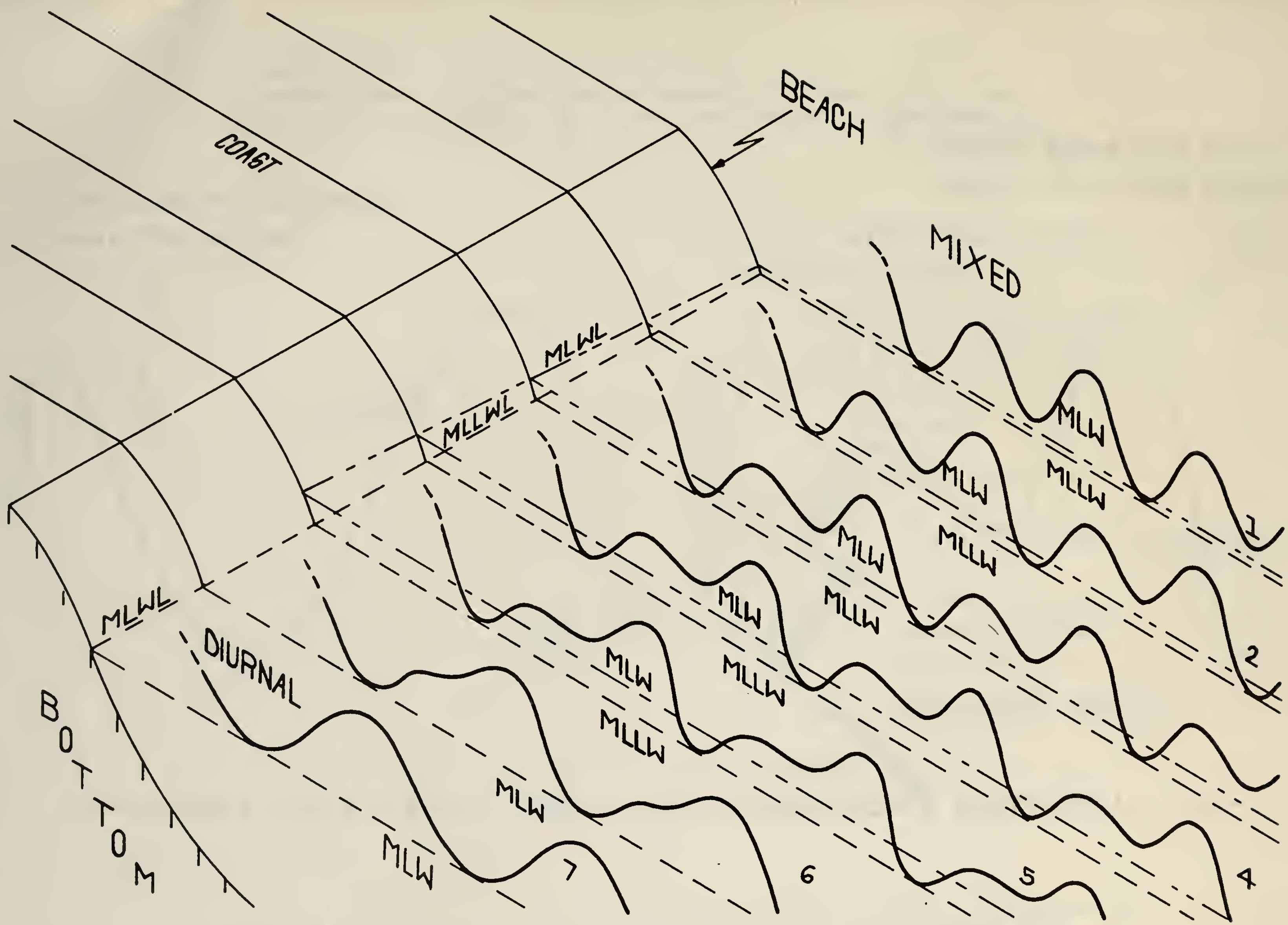


Figure 13.--Schematic of change in type of tide with distance along a coast

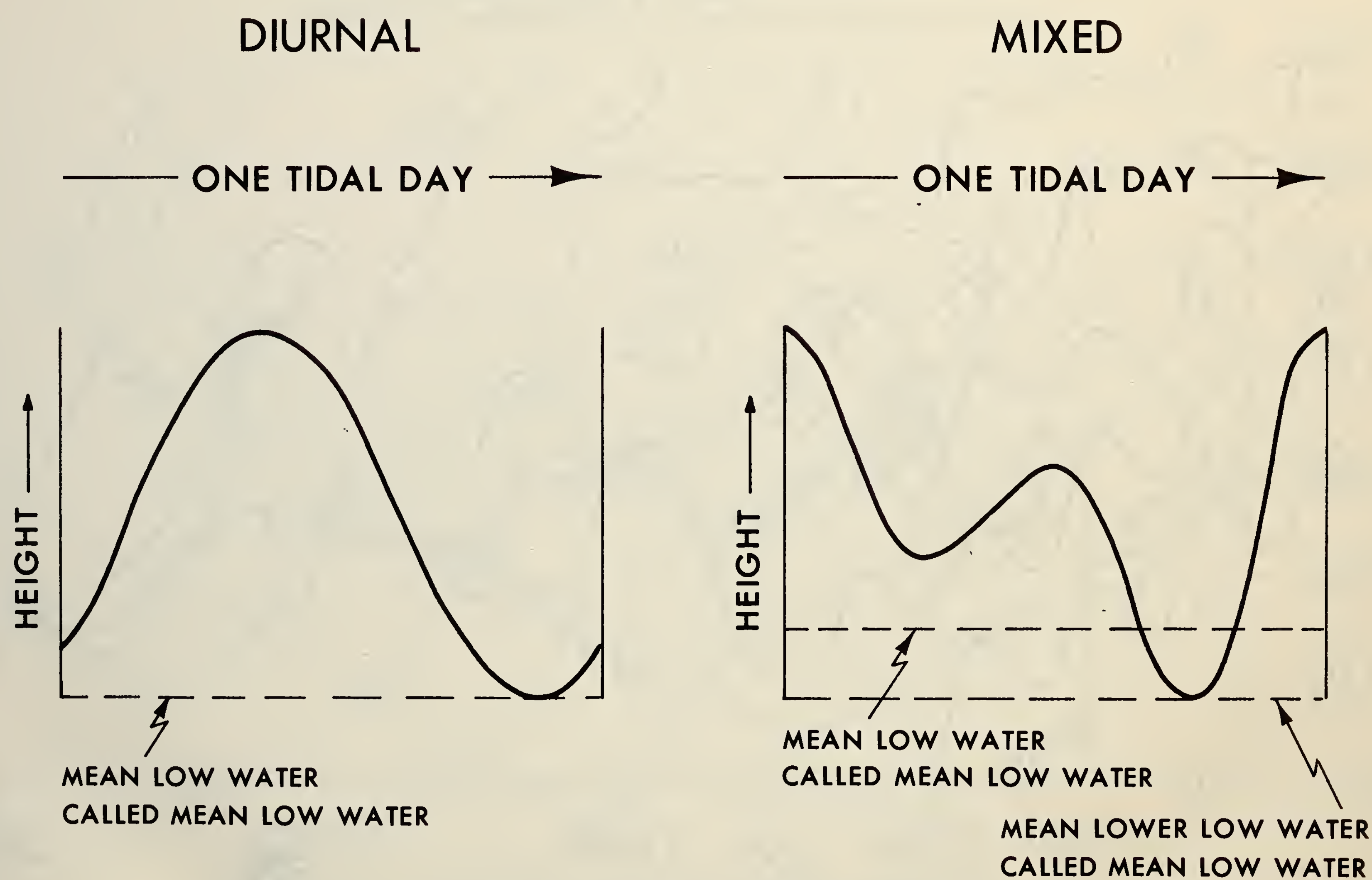


Figure 14.--Schematic of mixed and diurnal tides showing comparisons of tidal datum concepts, elevations, and names

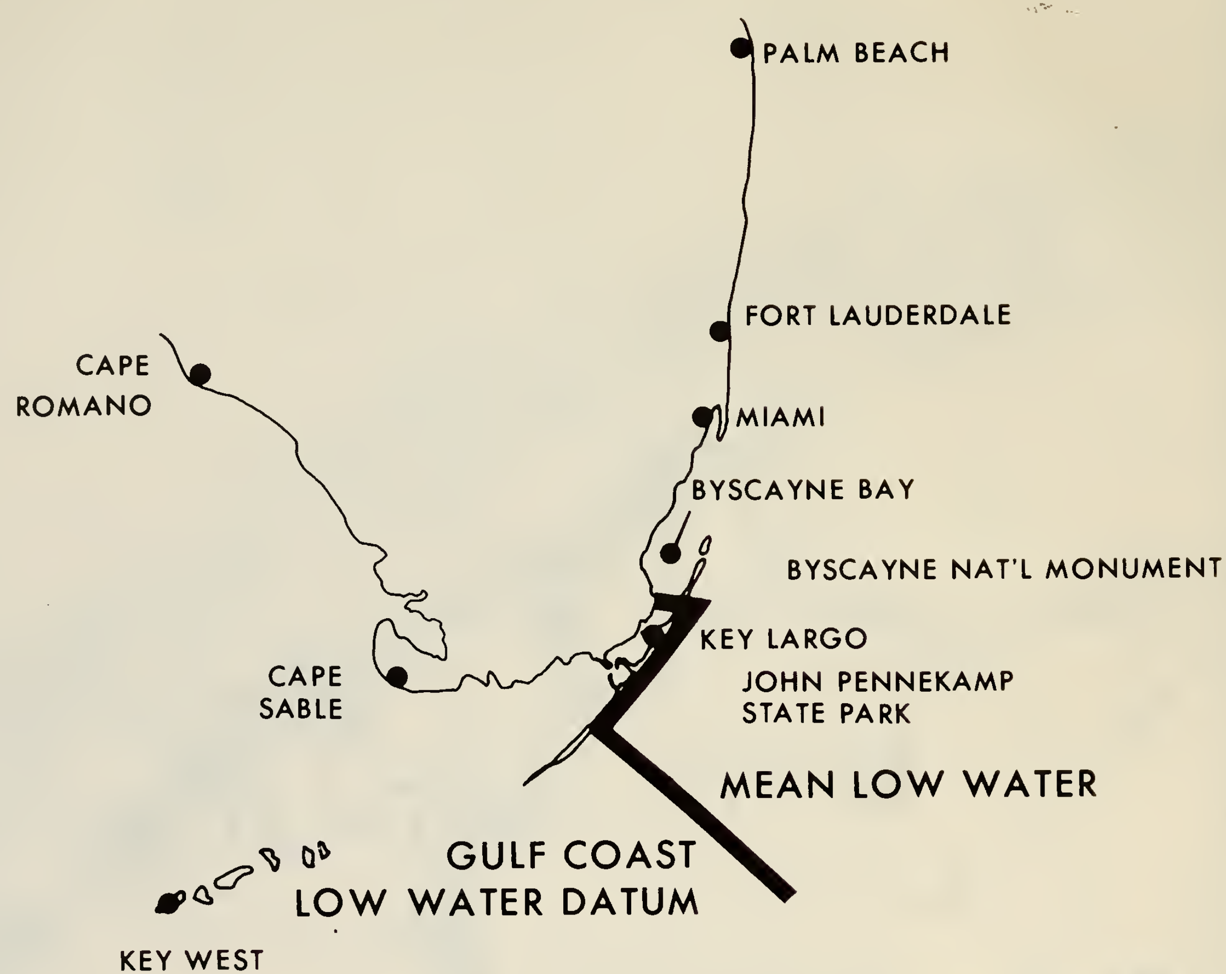


Figure 15.--Line segments separating Chart Datum of the Atlantic Coast (mean low water) from Chart Datum of the Gulf Coast (Gulf Coast Low Water Datum)

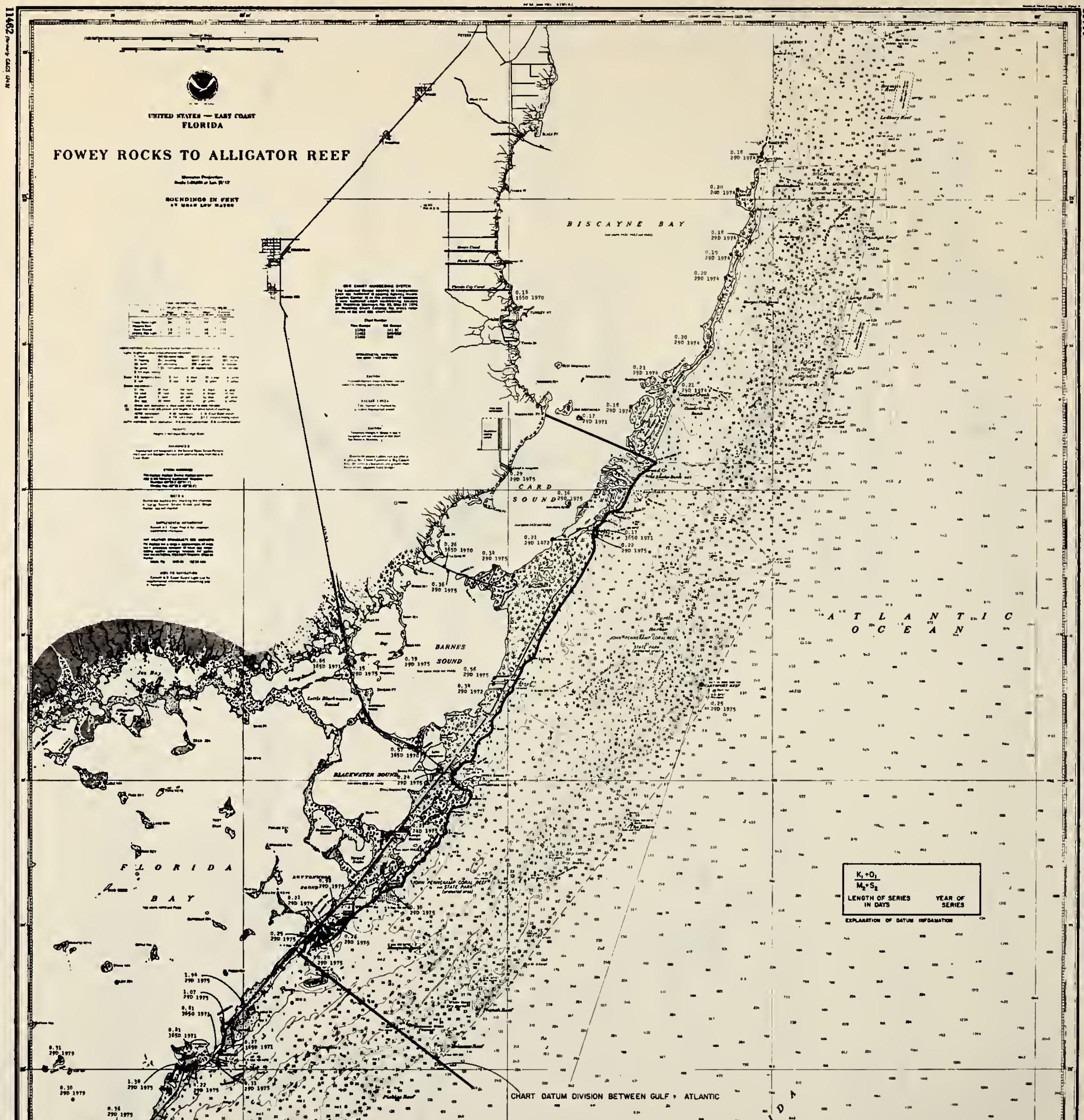


Figure 16.--Detail of line segments separating Chart Datum of the Atlantic Coast (mean low water) from Chart Datum of the Gulf Coast (Gulf Coast Low Water Datum).

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